BY JAY M. JACOBSMEYER, P.E.

Tackling interference at the site

Transmitter, receiver and passive intermodulation are the primary culprits

Part 1 of 2

Radio site co-location creates difficult interference problems. A site transmitter may operate with an effective radiated power as high as 3000 W, while site receivers must capture signals near the thermal noise floor. The power difference between transmitter and receiver can be as high as 200 dB. In most cases, the FCC limits radiated out-of-band emissions to no more than 60 dB of attenuation. The remaining 140 dB of interference rejection must be provided by the isolation inherent in the equipment and good practice at the site. Failure to adhere to minimum technical standards at the site almost certainly will result in harmful interference. This interference will make many receivers unusable and will desensitize others to the point where geographical coverage suffers.

Co-site interference comes from a variety of sources, including co-channel interference (rare), adjacent channel interference, transmitter intermodulation (IM), receiver intermodulation, and passive—or "rusty bolt"—IM. This series of articles is focused on the three types of IM interference:

- Transmitter-generated
- Receiver-generated
- Passive

We'll first review the physics and mathematics behind IM interference and then examine the mechanisms that create each of the three types of intermodulation.

All radio transmitters and receivers are non-linear to some degree, including FM transmitter amplifiers, which are purposely biased for Class C operation. Class C amplifiers are exceptionally good IM generators. Because they are non-linear, all transmitters will cause interfering signals to mix with harmonics of the transmit frequency to some degree, creating IM products.

An IM product is a problem for the site only if some part of the signal falls into the passband of one of the site's receivers and the signal has sufficient power to degrade receiver performance. Thus, we are interested in the frequency, bandwidth and power of the IM product. It turns out that IM frequencies can be computed easily with computer software, but IM power is quite difficult to predict.

The simplest intermodulation model assumes that two signals are multiplied in a non-linear device as shown in Figure 1.

Trigonometric identities tell us that for this simple model, there are two IM products, one with frequency equal to the sum of the original frequencies and the other with frequency equal to the difference of the original frequencies. In practice, IM products are more complex because the non-linearity also creates harmonics of the original frequencies. In general, the frequency of the IM products created by two signals are described mathematically using Equation 1.

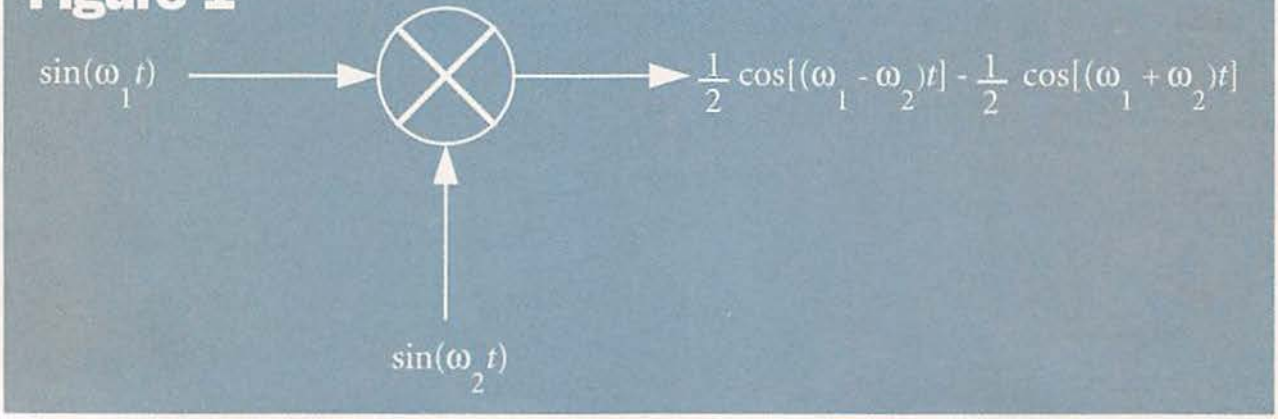
Equation 1

$$f_{IM} = mf_1 + nf_2$$

where f_1 is the frequency of the first signal and f_2 is the frequency of the second signal. The numbers m and n are integers and represent the harmonic order of f_1 and f_2, respectively. The order of the intermodulation product is $|m| + |n|$.

Intermodulation products also occur in combinations of three or more frequencies. The number of potential IM products grows rapidly with increasing product order. Simply computing all potential IM products is a non-trivial task if done manually. For example, a small site with just 10 transmitters will have 159,720 combinations of up to

Figure 1



three frequencies, 5th harmonic and below.

Multiplication in the time domain is equivalent to convolution in the frequency domain, which means the bandwidth of an IM product is wider than the bandwidth of either of the fundamental interfering signals. The actual spectral shape can be complicated, but a rule of thumb is that the nominal bandwidth of the IM product is equal to the product of the modulation bandwidth of each signal and the order of the IM product. For example, if FM signals f_1 and f_2 each have a frequency deviation of 3 kHz, the third-order IM product, $2f_1 - f_2$, will have a frequency deviation of 9 kHz.

We also are interested in the power levels of IM signals. Only those products that are 6 dB below the receiver noise floor or stronger will cause noticeable interference. An interfering signal f_2 must travel from its source to transmitter f_1's antenna, down the transmission line and through band-pass cavity filters and ferrite isolators (if any) to reach f_1's final amplifier stage.

At this point, f_2 probably will see a poor impedance match and have poor return loss. The small signal that does get through to the final amplifier stage will undergo a mixing loss, and the resulting IM product will have a power level that is strictly less than the power level of f_2. The difference between the power level of f_2 at transmitter f_1 and the power level of the resulting IM product is known as the turn-around loss. Turn-around loss is sometimes referred to as conversion loss, but conversion loss also is equated with mixer loss, which does not include the effects of impedance mismatch that occurs when f_2 is offset significantly from f_1.

The process for analyzing transmitter IM interference requires that one first gather detailed information on the antenna and transmission line configurations, transmitter turn-around loss, transmitter modulation bandwidths, cavity filters (existing and proposed), ferrite isolators, and receiver bandwidths. If the calculated IM interference is not below receiver threshold, the radio engineer must analyze antenna placement, cavity filter and isolator options to provide additional isolation.

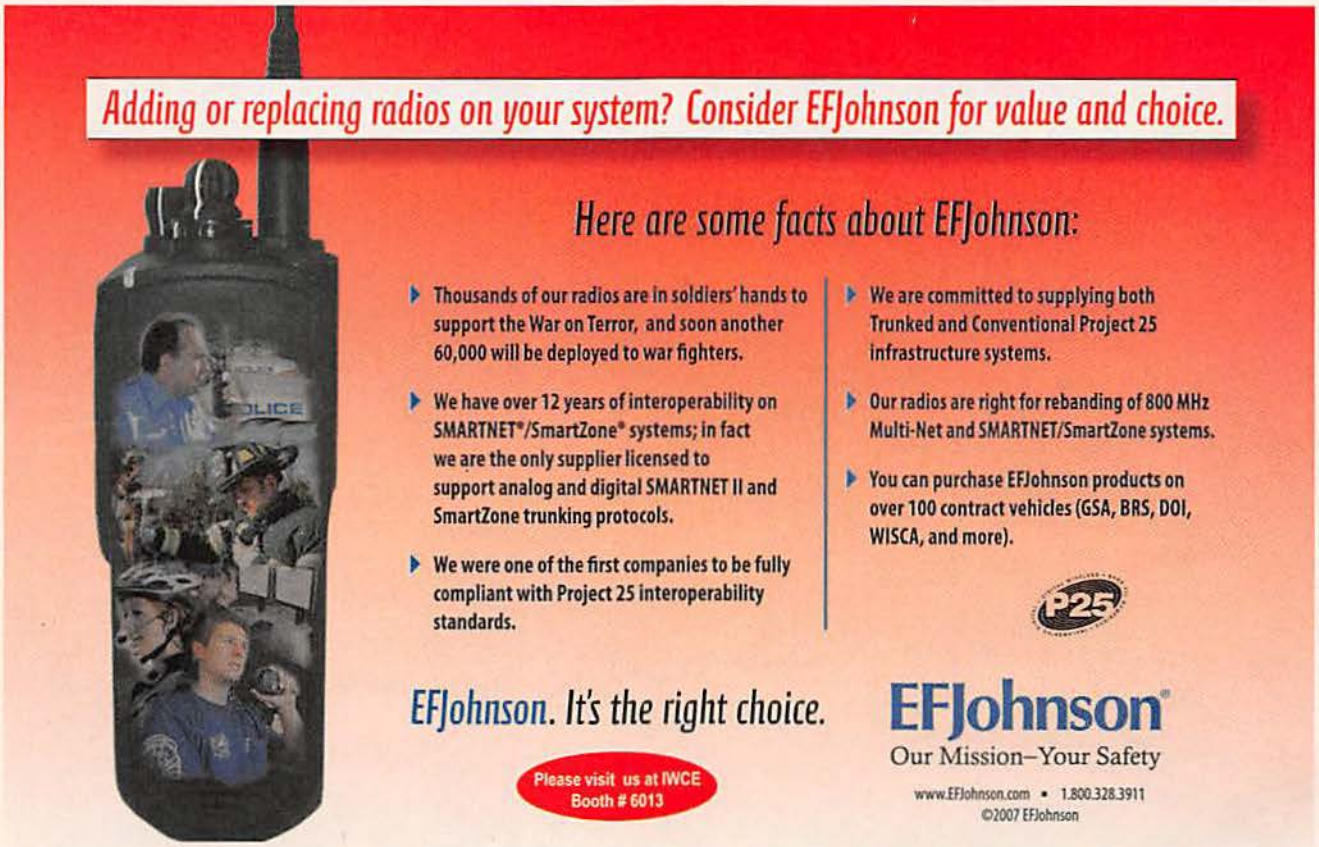
Equation 2

$$f_{IM} = 2f_1 - f_2 = 831.970 \text{ MHz}$$

To illustrate this process, consider a simple example of transmitter intermodulation. Our site has two transmitters and one receiver, as shown in Figure 2 on page 38.

The 930.050 MHz paging transmitter (TX B, f_2) causes an IM product to be generated in a cellular base station (TX A, f_1 = 881.010 MHz). The IM product, which is shown mathematically in Equation 2, is in the cellular A band (RX, 831.970 MHz).

This product is more than 50 MHz from the TX A frequency, and the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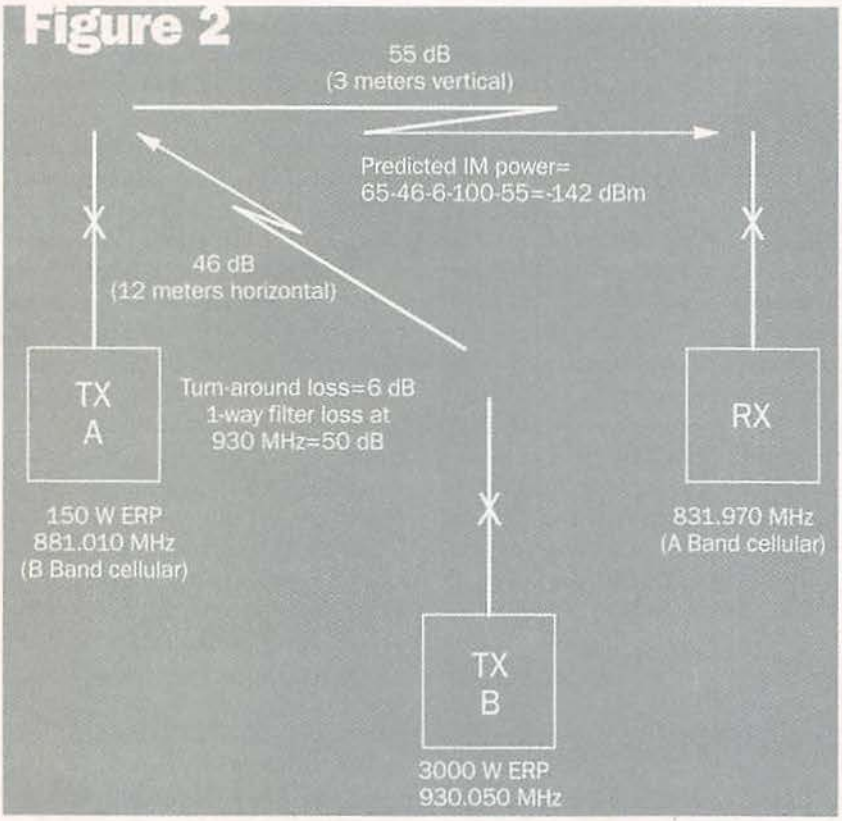

transmitter combiner in TX A should provide more than 100 dB of two-way isolation. When the antenna coupling losses, conversion loss, and filter loss are summed, the IM power at the receiver is -142 dBm, which is well below the receiver noise floor and therefore negligible (see Figure 2). Although this example had a happy ending, it illustrates the importance of bandpass filters on transmitters. Without the filter at TX A, the IM product would be -42 dBm and strong enough to wipe out the receiver.

Receiver IM calculations are performed in much the same way as transmitter IM. The mathematical relationships are identical, but the physical mechanism is different. Now the receiver acts as the non-linear device that creates the IM product. Because the IM product is created in the receiver, as opposed to a transmitter, we don't have the additional isolation from antenna separa-

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tion between the IM source and the receiver, as we had in the transmitter IM case.

There are two important types of receiver IM. In the first type, IM occurs between strictly external frequencies. The receiver simply acts as the mixing device. This type of IM is routinely measured at the factory for the third order, or $2f_1 - f_2$ case (where f_1 and f_2 are external frequencies). This test is sometimes called the two-tone intermodulation test. The results of this test can be used to determine the third-order IM rejection capability of the receiver.

In the second case, the receiver also introduces mixing frequencies, usually harmonics of the receiver's local oscillator, and the IM product is a combination of external and internal frequencies. This type of IM is more difficult to predict because local oscillator frequencies are not always known.

The key to eliminating receiver IM is to reduce the amplitude of interfering signals at the receiver front end. Cavity filters are the preferred tools, but sometimes antenna separation or other forms of antenna isolation are required.

It is important to isolate the source of IM interference before implementing solutions. Filters at the receiver will not solve transmitter intermodulation; similarly, filters at the transmitter will not solve receiver IM.

Probably the most difficult IM problem is passive IM (PIM), which occurs when two or more frequencies mix in a non-active device such as an antenna, loose joint, mating between dissimilar metals, or micro gaps between metal surfaces. Often the culprit is an antenna, especially a transmit antenna because the high currents flowing in the antenna elements make it a more efficient IM generator.

PIM tends to be broadband, and it cannot be corrected with filters or ferrite isolators. Prevention is the best cure for PIM. One should use antennas and connectors with low PIM. DIN connectors are preferred over N connectors. All connectors should use linear materials such as silver, gold and brass. Avoid nickel-plated connectors. Remove unused hardware and transmission lines from the tower and ensure all mechanical connectors and tight and free of corrosion. ■

Part 2: Common IM problems, real-world examples, and solutions.

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BY JAY M. JACOBSMEYER, P.E.

Solving intermodulation interference

Common problems, real-world examples and solutions

Part 2 of 2

Last month we laid the groundwork for understanding intermodulation interference at colocation sites. This month we'll illustrate some common problems with real-world examples and suggest some practical solutions.

Example 1: Interference from AM station. It may be hard to believe, but an AM station operating at 1040 kHz actually caused interference to a U.S. Postal Service repeater operating in the VHF band. The USPS repeater transmitted on 164.175 MHz and received on 166.250 MHz, and it employed a private line (PL) tone. The symptom resembled a stuck microphone. After the first user keyed his or her portable radio, the repeater remained keyed indefinitely. Users could hear white noise in the background and assumed the repeater was busy and unavailable. In reality, a modest uplink signal would recapture the repeater, but users were not aware of this fact and assumed the repeater was unusable.

An AM broadcast tower, operating on 1040 kHz, was located a few blocks from the post office. A quick look at potential IM products revealed the following: 164.175 + 2(1.040) = 166.255 MHz, only 5 kHz from the repeater receive frequency. Because the repeater employed good filters and a ferrite isolator, the consulting engineer concluded that the likely source of the IM product was passive IM in the repeater's antenna. The IM product did not create enough distortion to significantly alter the PL tone, so the site receiver always detected a valid tone and kept the repeater keyed. The antenna had recently been replaced to no avail and there was no enthusiasm for a second replacement, so the radio shop programmed different PL tones on the transmit and receive frequencies and the problem disappeared.

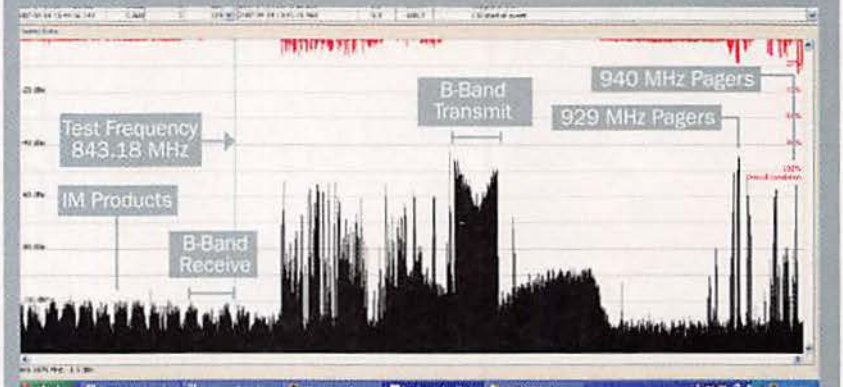
Example 2: Channel 23 (TV) interference to GPS L1 channel. The Global Positioning System (GPS) employs two main radio channels, L1 and L2. Civilian GPS receivers rely primarily on the L1 channel, which is a 1 megachip per second spread spectrum signal centered on 1575.47 MHz. A mountaintop site in Colorado is home to both Channel 23 and a nationwide paging company that uses GPS to synchronize its simulcast paging network. The visual carrier for Channel 23 is 525.25 MHz, and the third harmonic of this carrier is 1575.75 MHz, well within the 1 MHz bandwidth of the L1 channel. Immediately after Channel 23 went on the air, the paging station lost synchronization and the company's technician called the consulting engineer for help. A better lowpass filter on the Channel 23 transmitter helped somewhat, but the problem persisted because the GPS receiver did not adequately filter the television signal and the third harmonic of Channel 23 also was created in the receiver front end. The receiver was replaced with one that included a better front end filter. Note that in this case, both transmitter-generated harmonics and receiver-generated harmonics existed. There is not always a single source of IM interference.

The second harmonic of the aural carrier of Channel 66 (TV) falls on 1575.5 MHz, and it also can interfere with GPS L1 receivers.

Example 3: 900 MHz pager interference to the B-band cellular operator. This problem occurred at two different cell sites, and although 900 MHz pagers were involved in both cases, the physical interference mechanism was quite different at each site.

It is fairly well known in the cellular industry that paging transmitters operating in the 929–932 MHz bands can cause interference to the B-band cellular operator. The B-band operator receives in the bands 835–845 MHz, 846.5–849 MHz and transmits in the bands 880–890 MHz and 891.5–894 MHz. Many B-band operators employ the TIA-95 CDMA airlink standard with 1.25 MHz-wide channels. If one of these CDMA carriers is transmitting on 886.44 MHz and a nearby paging transmitter is operating on 929.5625 MHz, a potential IM product results: 2(886.44) – 929.5625 = 843.3175 MHz, which falls in the reverse link band of the cellular operator. Because the transmit signal

Figure 1



is 1.25 MHz wide, the IM product will be at least 1.25 MHz wide (closer to 2.5 MHz in this case) and at least two CDMA receive channels are affected by this interference.

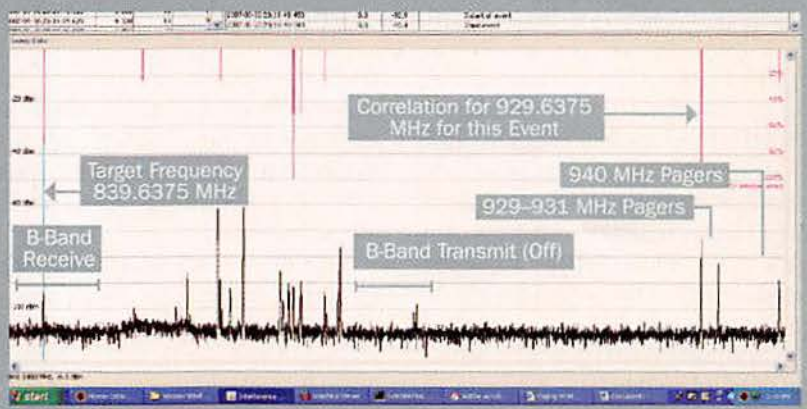
At the first site, the interference was intermittent and the consulting engineer set up an automated test with a spectrum analyzer connected to the diversity antenna on the affected sector. The control software was set to store each trace whenever energy appeared above a pre-determined threshold on a frequency known to be out-of-service. Figure 1 shows a spectrum analyzer trace for an interference event at this site. Note that the interfering signals are similar to individual CDMA carriers, but roughly twice as wide and with a more rounded shape.

This wider bandwidth and rounded shape is consistent with the second harmonic of a CDMA signal. Note that interferers appear at regular intervals and the interference extends well below the cellular operator's receive band. The reader will also notice a notch exists in the B-band transmit spectrum. This notch is from a notch filter inserted in front of the spectrum analyzer to suppress the transmit signals and thereby prevent the analyzer front end from being driven into saturation.

Further tests showed that the IM products at this site only occurred when the cellular operator was transmitting. After eliminating both transmitter intermodulation and receiver intermodulation as sources, the operator concluded that the cellular antennas were generating passive IM and should be replaced.

The second site is congested with FM broadcast, TV broadcast, VHF repeaters, UHF repeaters, 800 MHz public safety radio, 800 MHz ESMR, 800 MHz cellular, 900 MHz paging and PCS. There are 14 paging transmitters at this site, and measured levels at the affected sector antenna (before filtering) are as high as 0 dBm. The paging antennas are less than 50 feet from the B-Band sector antennas. Unlike the first site, interference at this site was still present when the cellular operator was not transmitting. Also, the interference was narrowband. (See Figure 2.)

Figure 2



An examination of the data showed that the interference always fell exactly 90 MHz below one of three 929 MHz or 931 MHz paging frequencies in use at the site. Further investigation revealed that the paging transmitters employed a 90 MHz intermediate frequency and upconverted the signal from there. Thus, either the local oscillator for the upconversion or an IM product was the source of the interference. The paging transmitters lacked adequate bandpass filters which would have prevented this problem. It is interesting to note that the cellular antennas at the second site were exposed to much higher levels from paging transmitters than at the first site, but they did not create passive IM interference. Thus, the level of PIM rejection differs widely between manufacturers.

Example 4: Image frequency interference to public-safety receiver. Image frequency interference is a form of receiver IM that often is overlooked. Consider a superheterodyne receiver with a first IF of f_{IF} tuned to frequency f_{RF}. The local oscillator (LO) frequency is either $LO = f_{RF} + f_{IF}$ or $LO = f_{RF} - f_{IF}$, depending on the receiver design. An image frequency, f_{IMAGE}, is an undesired frequency that is exactly 2 f_{IF} above or below the tuned frequency, f_{RF}, for LO frequencies below or above the tuned frequency, respectively. For the most part, the mixer does not distinguish between a tuned frequency and an image frequency and it will generate an IF signal from either. The key to eliminating image frequency interference is to employ a good filter at the receiver front end to attenuate the image frequency.

Consider this example: If the tuned frequency is 807.25 and the IF is 45 MHz, the image frequency is 807.25 – 2(45) = 717.25, which is the visual carrier for Channel 55 (TV). Thus, if the receiver front-end filter does not adequately attenuate 717.25 MHz and the television visual carrier is strong, harmful image frequency interference will occur. Of course, image frequency interference from analog television transmitters operating on Channel 55 will not exist after Feb. 17, 2009, when the digital television transition is complete and all television stations will be digital and will be confined to Channels 2–51 (with a few exceptions). ■

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